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ADVANCES AND EXPERIENCE WITH TELEOPERATED SYSTEMS INCORPORATING REMOTE PRESENCE

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INTRODUCTION

The Naval Ocean Systems Center (NOSC) Hawaii Laboratory has a long standing program in research and development on teleoperated systems. Recent work is summarized in the literature [1, 2, 3]. Our interest in teleoperated systems is removing the human from hazardous environments. Our research and development in this area has the objective of maximizing system capabilities and minimizing operator work load and training by providing the system operator with a sense of remote presence. Remote presence can be described as:

"..the perception of actually being at the remote location."

The degree of 'presence' achieved is determined by: (1) the fidelity and/or richness of the sensory information, (2) the ability to control the relation of the sensors to the remote environment, and (3) the ability to physically interact with the remote environment.

The cost of teleoperation in a system is increased complexity and, based on present technology, a reduced capability for action. Complexity arises from the requirement to provide the remote operator with sensory and control interfaces. Reduced capability for action is a result of the reduced information to the operator resulting from the limitations of the sensors, displays, and control mechanisms. One focus of our research is to improve these technologies.

This paper discusses progress at the Hawaii Laboratory over the past three years in the development of three teleoperated systems: the Advanced Tethered Vehicle (ATV), the TeleOperated Vehicle (TOV) and the TeleOperator/telePresence System (TOPS). We will comment on experience to date with these systems, pointing to the need for additional sensory information by the remote system operator to achieve increased performance. Each of these systems addresses a different mission, but all share common approaches to subsystem design and to various degrees incorporate remote presence. ATV and TOV utilize a fiber optic data link for high band width, small size, ruggedness, and in the case of the TOV, jam resistance and covertness.

DISCUSSION

Advanced Tethered Vehicle (ATV)

The objective of the ATV is to provide the Navy with the capability to perform work to ocean depths of 20,000 feet. ATV is a self-contained, remotely operated undersea system [4]. Since ATV will be operated and maintained by Navy personnel the design was based on mature technology to insure a high level of system reliability and availability. The ATV system, figure 1, consists of five main components: a neutrally buoyant submersible vehicle, tether cable, handling system, control station and auxiliary equipment.

The vehicle work package, figure 2, consists of two manipulators, four television (TV) cameras, a 35-mm film camera and strobe light, and a variety of tools and lights. The manipulators are identical master-slave units incorporating force feedback. Of the four TV cameras, two are used in a stereo pair, one has a zoom lens, and one acts as a view finder for the film camera. The stereo pair and zoom cameras are mounted on pan and tilt units. A suite of hydraulically powered tools is mounted on the support tray below the manipulators and includes a rotary drive to which an abrasive cutoff wheel, drill, or impact wrench can be attached and independent linear tools consisting of a spreader, cable cutter, jack and grabber.

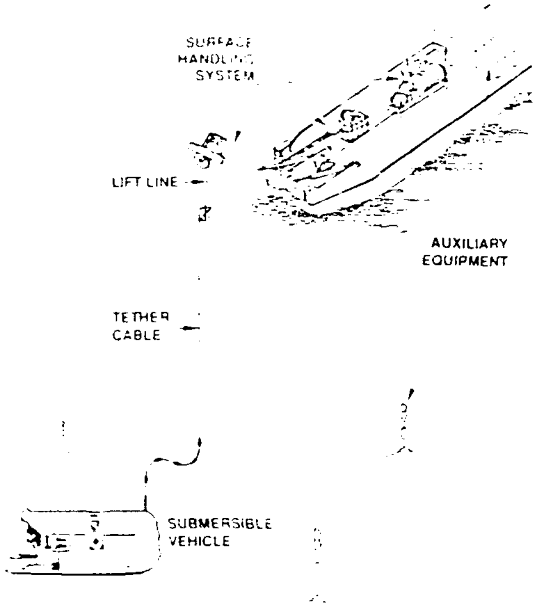

Fig. 1 ATV System Configuration

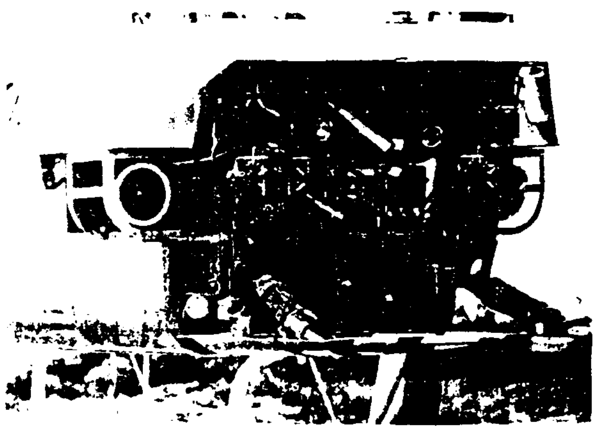

Fig. 2 ATV Work Package

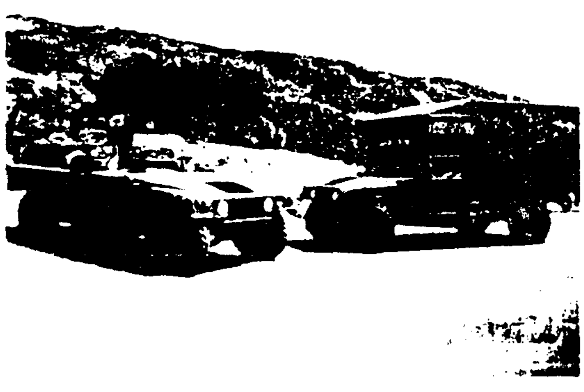

Fig. 3 TOV and Control Van

The subsystems supporting teleoperation, i.e. sensors, displays, telemetry, and control interfaces are summarized in Table 1. The primary control interface with the vehicle are through its joystick propulsion control and the dual, force feedback manipulator controllers. The primary sensory displays include the flat panel stereo TV display, the sonar display , the navigation display and force feedback from the manipulator controllers. Over 240 hours of operation at depths to 20,600 ft have been logged on the system during test and evaluation. Experience to date has demonstrated that the system meets its reliability and effectiveness objectives. Operations with the work system have demonstrated that the operators can effectively perform the types of tasks required for deep ocean work, e.g. attachment, object manipulation, tool operation,etc.

TeleOperated Vehicle (TOV)

The objective of the TOV is to provide Marine Corps and Army personnel with a prototype unmanned ground vehicle (UGV) system which can be used in training exercises and operations to assess UGV systems' military worth, develop concepts of employment, and develop an experience base to guide future development.

The TOV is a remotely operated system which permits an operator to extend his sensory, motor function, and problem-solving skills to a vehicle located up to 30 kilometers away [5, 6]. The TOV system consists of a Remote Vehicle and a Control Station, figure 3. An operator controls the TOV system using displays and controls located in the Control Station. Visual and auditory displays have been designed to facilitate understanding of the vehicle's situation. Hand and foot operated controls, analogous to automotive vehicle controls, are used to control vehicle functions. A fiber optic data link allows physical separation of the operator from hazards encountered by the remote vehicle. Based on the High Mobility Multi Wheeled Vehicle (HMMWV), TOV is capable of high transit speeds and can traverse severe off-road terrain. A mission-specific, add-on subsystem for Reconnaissance, Surveillance, and Target Acquisition (RSTA) has been developed.

The subsystems supporting teleoperation of TOV are summarized in Table 1. The control station specified in the table provides an interface similar to what is provided in the actual vehicle, i.e. steering wheel, throttle, gear shift, and seat. These controls are presented to the operator in the same relative position they occupy in the HMMWV, figure 4. An alternate controller has been developed which fits in several man portable containers and is easily set up and operated in the field, figure 5. Driving controls are presented to the operator using a motorcycle type controller that integrates the throttle, brakes, gear shift, ignition and starting controls. This design was selected after extensive field testing which considered joy-stick steering, steering wheel, and the motorcycle handle bar like steering. The integrated motorcycle-like system was selected based on performance, compactness and ease of use in the field. Both control approaches use a helmet mounted, stereo display. This display is described extensively in references [7, 8, 9].

NOSC has constructed three TOV systems. Two systems are operated in support of military exercises and demonstrations while the third remains at the NOSC Hawaii Laboratory where it supports further research and development. As a result of operation of these systems an extensive experience base has been developed.

Vision is the primary sensory mode for remote driving. Extensive research has been performed to evaluate various types of displays and to determine their influence on vehicle operation [8, 9]. Field testing with the vehicles has provided additional insight into vision system performance and requirements. For effective high speed driving in rough terrain, head coupled stereo vision is important to performance for recognition of terrain features, such as rocks, depressions and ditches [8, 9]. Field of view (FOV) is also important since we obtain most of our navigation cues from peripheral vision. For existing sensors and

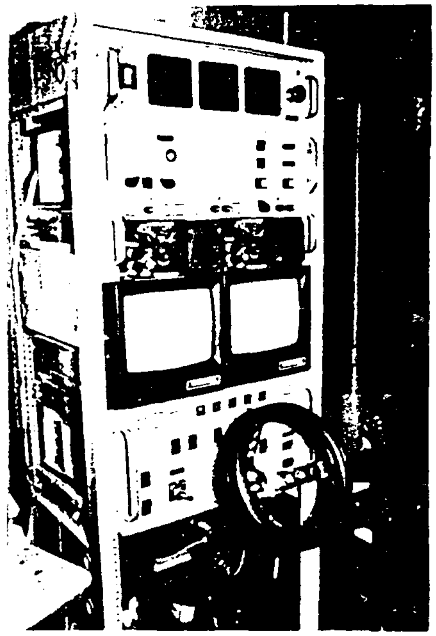

Fig. 4 TOV Control Station

Fig. 5 TOV Portable Control Station

displays, FOV is a trade-off for display resolution. Experience at NOSC indicates that if offered a 40^{0} FOV with relatively high resolution or a 55^{0} FOV with lower resolution a vehicle operator will select the higher resolution display if head coupling is incorporated. Our experience and that of others [10] indicates that for a fixed viewing system, a 40^{0} FOV is inadequate for driving in complex environments. With a head-coupled system operators typically pan the viewing system to get a higher effective FOV. Head coupling appears to provide the required spatial awareness. Color vision is also preferred over monochrome when driving in rough terrain [8, 10] because it provides increased information to the operator allowing discrimination of objects in grass, depressions, shadows, etc. It is important that sensory displays be in one to one correspondence with what is sensed on the vehicle. This is especially true for the display system magnification and head motion.

Experience gained with these systems indicates that for performance and safety the operators require additional sensory data on the remote vehicles' roll and pitch orientation (situational awareness). An intuitive display of vehicle attitude is required to allow the operator to perceive vehicle attitude on hills and side slopes. TOV operators have experienced several near accidents because they were not aware of the vehicle being on a steep grade. Experience at Sandia National Laboratory also indicates that the majority of accidents with teleoperated vehicles can be attributed to a lack of situational awareness [10].

TeleOperator/telePresence System (TOPS)

The objective of the TOPS project is to develop an anthropomorphic manipulator system and a high resolution stereo vision system to provide a remote work capability equivalent to an undersea diver. The manipulator system has been developed by a team made up of SARCOS Research Corp. and the Center for Engineering Design at the University of Utah. The helmet-mounted display system was produced by Wright-Patterson Air Force Base based on their work in the LHX Helicopter program. Figure 6 shows the master and slave system with the operator using the exoskeletal controller and the helmet mounted display. The manipulator system includes a 16 degree of freedom (DOF) hand/arm, a three DOF torso and a three DOF neck to provide the telerobot with the job site mobility to perform effective work.

Teleoperation subsystems are summarized in Table 1. The remote manipulator (slave) is kinematically equivalent to a human. The manipulator and exoskeletal controller incorporate bilateral force and position feedback, i.e. the force and position of one are reflected at the other. Force and position sensors are mounted at all the joints.

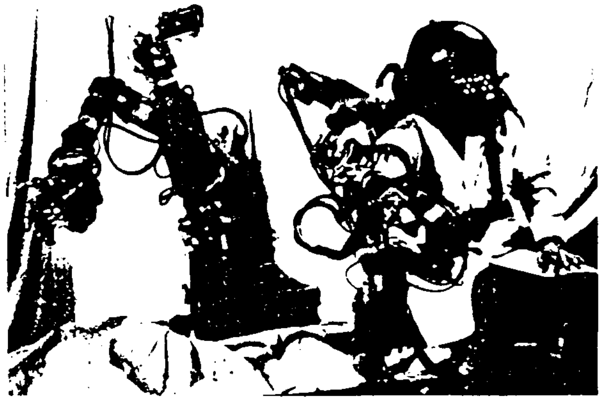

Fig. 6 TOPS manipulator and controller

The manipulator system is presently in the refinement and tuning stage after which a full range of laboratory testing is planned. Anecdotal information from initial testing of the display system with a seven DOF manipulator available at the Hawaii Laboratory indicates that it provides the operator with a sense of remote presence. For these tests, the stereo camera pair was mounted on a simple pan and tilt unit that followed the operator's head motions. Insights gained to date include: (1) the operators would prefer a manipulator with an additional degree of freedom at the shoulder (abduction/adduction), (2) the operators desired the ability to move the camera laterally and fore and aft (torso motion) to get differing perspectives on the task, and (3) the tests demonstrated that the high resolution stereo display significantly enhanced the ability to perform some tasks.

SUMMARY AND FUTURE DIRECTION

The level of presence required in a teleoperated system is a function of its intended use. It has been shown that through inclusion of remote presence technology the task of operating a telerobot can be simplified and made more efficient. We have found that remote ground vehicle operators require additional sensory information, particularly in the area of attitude and location. Operators easily get lost, and have no feeling for vehicle attitude or location.

There is a need for improved vision technology. Remote work requires good resolution and can accept a limited field of view. High speed driving of remote vehicles requires high central resolution and a wide FOV. TOV system drivers have the equivalent of 20/95 vision. Visual acuity of 20/40 is the minimum required by many U.S. driving laws [8]. Small, high resolution, low cost, color displays are required.

NOSC will continue to develop teleoperators for the U.S. Department of Defense. Our experience has shown that the design of the operator interface is critical to the success and performance of these systems. One approach we wish to investigate is the use of 'Virtual World' technology to fuse sensory data and present it to the operator in an integrated context that is natural for the task. The first application under consideration for this approach is in integrating the information available to undersea teleoperated vehicle operators from their sonar, navigation and video sensors. Conceptually this information would be presented to the operator through a head mounted display system, such as is used in TOPS, but the scene would be computer generated. The scene presented to the wearer would be a graphical representation of the world model derived from the combined sensor inputs. Since the operator would be looking into the model from a computer generated vantage point he could choose his point of view to be on the vehicle or outside of it to navigate and maintain an intuitive sense of where the vehicle is and has been. This ability to select a view point should aid in mission planning and route planning.

TABLE 1
SUBSYSTEM SPECIFICATIONS

SUBSYSTEM	ATV	TOV	TOPS
MOBILITY			
CONTROL	Joy Stick - 4 DOF	HMMWV Replica	Exoskeletal
NAVIGATION	Long Base Line	SatNav	None
Display	Graphic - Plan view	Graphic	
SENSORY DISPLAY			
VISION	Monochrome, 512 lines	Monochrome, 512 lines	Monochrome, 1023 ln.
Display	Flat Panel Stereo	Helmet Mounted Stereo	Helmet Mounted Stereo
FOV	60 Degrees	40 Degrees	70 Degrees
Direction	Joy Stick Directed	Helmet Tracking	Helmet Tracking
AUDIO	Monaural	Binaural	Binaural
MANIPULATION	Terminus Control	None	Exoskeletal Control
	Force feedback		Force & Position
	5 lb resolution		1.5 oz resolution
MANIPULATION			
MANUFACTURER	Western Space & Marine	NONE	SARCOS
DEGREES OF FREEDOM	7 Total		22 Total
Neck	–		3
Torso	–		3
Arm	6		7
Hand	1		9
DATA LINK			
TYPE	Fiber Optic	Fiber Optic	Analog Cable
DATA RATE	200 Mbs Bidirectional	200 Mbs Bidirectional	800 Mbs Equivalent
LENGTH	23000 ft	30 Km	50 ft

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